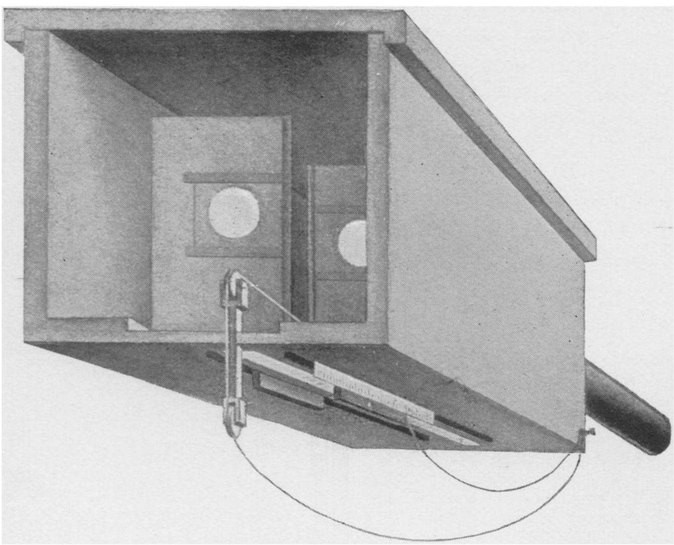
THE INFLUENCE OF THE COLOR OF SURFACES ON OUR ESTIMATION OF THEIR MAGNITUDE.

By J. O. Quantz, B. A.

One of the most generally known optical illusions is the apparently increased diameter of the rising moon. For this phenomenon there are different explanations. It is said that if the moon be near the horizon, we have the opportunity of comparing it with objects at a distance, but well known to us. When the moon is high in the sky, near or at the zenith, —where the diameter is really a little greater, on account of its being nearly 4,000 miles nearer,—we have no such opportunity. This explanation, however, is not satisfactory; for if we see the high-standing moon re-appear behind steep rocks or high buildings, the phenomenon does not occur.

A more satisfactory explanation is this: We project the celestial bodies on the surface of the sky. But the apparent form of the sky is not that of a sphere, but of a flatter vault, like a watch-case. Now, we attribute to all objects which we project on a surface thesize which the corresponding part of the surface itself would have at the distance at which we think we see it.

Whatever the true explanation may be, there is one point which has been overlooked. When the moon appears very large at the horizon, she has always a strongly orange or reddish color. The same is the case with the rising and setting sun; and it can really be observed that the phenomenon is less conspicuous when the reddish color is absent. This, however, does not prove that the redness of the moon is one of the causes of the illusion. The two phenomena may perhaps be traced back to the same cause. It may be, for example, that the moisture of the atmosphere, which causes



the red color by its absorption of the more refrangible rays of light, is also, on account of the dimness in which distant objects appear through it, the cause of our illusion. But it remains a question of interest whether this red color has anything to do with the geometrical optical illusion. From this particular phenomenon arises a more general question: Has the quality of light sensations an influence on the estimation of size? With a view to the solution of this problem, the experiments reported in the following pages were undertaken.

The apparatus used, of which the accompanying figure gives an idea, consisted of a large case, having one end open, and at the other an observing-tube. The case was painted on the inside a dead black to prevent its reflecting light; the tube was covered inside and outside with black velvet. Within this case were two movable black screens in a plane at right angles to the line of vision. Each of these screens was provided with an opening, in order to receive the objects. The latter were diaphragms of thin brass with a circular aperture, behind which were placed gelatine papers of different colors. In order to prevent the light from passing between the screens, the latter were provided at their inside edge with strips of black velvet, which overlapped each other without hampering the movement.

In a few experiments where two white circles were compared, the circles were equal, but for the others unequal; so that when they appeared to be of the same magnitude, they would not be at the same distance from the observer's eye, *i. e.*, not in the same plane. This excluded the possibility of judging the discs to be equal by noticing that they were in the same plane. The right hand diaphragm was stationary, at a distance of 1,240 mm. from the eye of the observer; the left movable, running in a slit in the bottom of the case. This movement, in both directions, was made by means of pulleys at the open end of the case, remote from the observer, and cords attached to both ends of the frame supporting the diaphragm which contained the disc; so that the observer himself was able to regulate the distance. Outside and underneath the case, to admit of being seen without removing the lid, was a millimeter scale, zero being in the plane of the

TABLE I.

Apparent Color.	Composed of		Visible Part of the Spectrum.	Remarks.
	Colored Gelatine Films.	White Tissue Papers.		
Red,	1 purplish red, 1 orange,	1	Red end to 598 $\mu\mu$,	
Orange,	1 rose, 2 orange,	1	696 $\mu\mu$ — 580 $\mu\mu$,	Also weak traces of green near 515 $\mu\mu$.
Yellow,	4 yellow,	1	Red end —509 $\mu\mu$,	Near red end very weak.
Green,	2 green,	1	566 $\mu\mu$ — 512 $\mu\mu$,	
Blue-green,	2 blue, 1 green,	1	556 $\mu\mu$ — 434 $\mu\mu$,	
Blue,	2 blue,	1	536 $\mu\mu$ to the violet end,	
Violet,	2 (different) violet,	1	Whole spectrum visible, with exception of 614 $\mu\mu$ —539 $\mu\mu$,	
Purple,	2 violet, 1 magenta,	1	Red end—600 $\mu\mu$ and 462 $\mu\mu$ —violet end.	Violet end very faint.

fixed disc. The perpendicular part of the sled of the movable object, reaching down a little deeper than the scale, had an arrow-formed white mark, which served as an index. The whole apparatus was placed with the open side against a window with white ground-glass. Fig. 1 shows the arrangement seen from the open side. Each trial consisted simply in changing the position of the left disc to the point at which it *appeared* to be equal in magnitude to the right, and then recording its position. Each color was compared separately with white. A series of trials was made with two white discs to determine what variation might result, which was not due to color.

The quality of the colors used, according to a spectroscopical examination, is shown on the opposite page. The wave-lengths are obtained by graphical interpolation.

The method of calculation may be outlined thus: Figs. 2 and 3 show a horizontal section, Fig. 2 having the larger

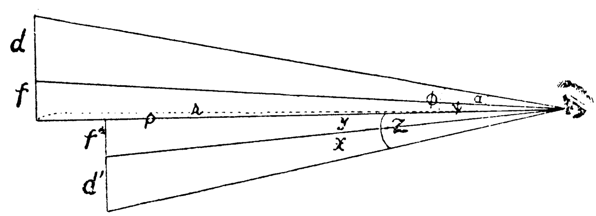


FIG. 2.

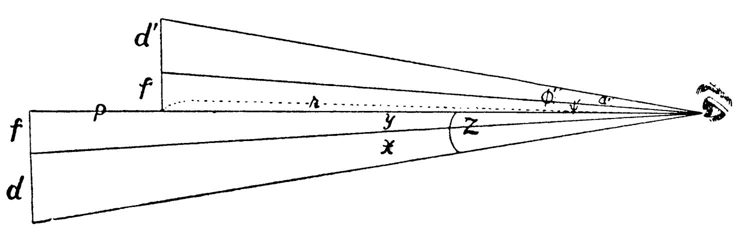


FIG. 3.

circle in the fixed position, and Fig. 3 the smaller. d is the diameter of the larger circle (40.575 mm.); d′ of smaller (36.703 mm.), which is therefore nearer the eye when they appear of equal magnitude; f half distance (19.5 mm.) between the discs; r distance of the eye (1.240 mm.) from the position of the normal disc (stationary at right side); a,

visual angle of larger disc in normal position; a', of smaller; ψ, visual angle of half distance between discs at normal position; $\phi = a + \psi$, $\phi' = a' + \psi$.

a (easily found by trigonometrical calculation by means of the formulæ:

$$\tan\phi = \frac{f+d}{r}$$
$$\tan\psi = \frac{f}{r}$$
$$a = \phi - \psi\,)$$

For the colors orange, blue-green, violet and purple:

$$a = 1^{\circ}\,52'\,21''.\,8$$

Similarly: $a'\,(\phi' - \psi\,) = 1^{\circ}\,41'\,39''.\,2$

The visual angles of the moved object and also the angular value of the mean variation were determined by means of the same formula. If we denote by ρ that distance of the movable object, in which it appears of equal size with the normal disc, by y and z the angular distances of the inner and outer edge of the movable disc from the median line, and finally by x the visual angle of the movable disc, then we have

$$\tan z = \frac{f+d'}{\rho} \text{ resp. } \frac{f+d}{\rho}$$
$$\tan y = \frac{f}{\rho}$$
$$\text{and } x = z - y$$

The angular value of the mean variation has been determined by the following procedure. Suppose the average of the registered values of a series of 50 or 100 single trials (ρ_1, ρ_2, ρ_3 . . . . ρ_n) to be ρ_m and the mean variation Δ. Now we compute the visual angle (x) for:

$$\rho = \rho_m$$
$$\rho = \rho_m + \Delta$$
$$\text{and } \rho = \rho_m - \Delta$$

Then the angular value of the mean variation will be

$$\frac{[x\ (\text{for } \rho_m + \Delta) - x\,(\text{for } \rho_m)\,] + [x(\text{for } \rho_m) - x(\text{for } \rho_m - \Delta)\,]}{2}$$

An equal number of trials was made with each eye. Each series of experiments was computed separately, and afterwards combined in tables. The series numbered I to IV under "Division of Experiments," in the subjoined tables, were arranged as follows: In I the colored circle was the

larger, and to the right, *i. e.*, stationary; II, right, and small; III, left, large; IV, left, small. Fig. 2 above thus represents the series I and IV, while Fig. 3 shows the position for II and III. For the colors, red, yellow, blue and green, there were only two divisions corresponding to IV and III respectively, the colored disc being always at the left. The experiments with these colors were made first, in 1893-94; all others were done in 1894-95.

For each series the average distance of the movable (left hand) disc was found, and the visual angle determined and compared with the angle of normal magnitude, *i. e.*, the angle subtending the fixed disc. The results are given under "Average Deviation from Normal Magnitude" in the tabulated statements. *Plus* indicates that the visual angle of the white disc was greater than that of the colored by so much, when they were judged to be equal; *minus*, that it was less; *i. e.*, in those marked *plus*, the color was overestimated, in *minus* it was underestimated.

In all the observations care was taken to exclude from the eye other light than that which entered through the observing-tube. The intensity of light was slightly greater on certain days than on others. But this made no appreciable difference in results, as was proved by a set of experiments undertaken for the purpose, with different light-intensities. Also the intensity-relation between the colored and uncolored disc was changed in order to see its influence on the judgment. The result was negative. There was made, *e. g.*, for the color blue, one series where the colored disc was compared with a white, composed of three tissue papers; while in an other series the white consisted of four tissue papers. The difference between the two series was smaller than the mean variation. This proves that irradiation and small differences in the relative light-intensities have under such circumstances, where bright objects are seen before an entirely dark background, no effect on the estimation of surface-magnitude. But after all, we chose our intensities as near to equality as it is possible to get them by comparison of differently colored surfaces in transmitted light. The two observed circles were exactly on a level with, each other to prevent the possibility

of one being enlarged by occupying a higher position, and being thus projected on a different retinal region. The difference in lateral indirect vision, too, was almost entirely excluded, by the circles being placed equally distant to the right and the left of the centre of vision. The trials were made throughout with the movable disc advancing and receding alternately, so that any possible error from this source was ruled out.

The tabulated results follow in Tables II-X (pages 33 to 38).

The conclusions previously reached were modified by an unexpected discovery, viz., that the moved circle was always underestimated. This is confirmed, too, by the trials in which both discs were white, the movable one, in order to appear equal to the other, requiring a visual angle greater by 28″.7 to 4′ 58″.8, and only in one instance less, and then but 5″.5. On an average the moved disc was underestimated by K. 1′ 31″.8, and by Q. 2′ 28″.8875. We found also, on thinking back, that the experimenter had in almost every case stopped, after judging the circles to be equal while slowly moving the one, and then observing them at rest was not satisfied with their equality, and again changed their relative positions a little. The underestimation of the surface-magnitude of a bright object on dark ground seems according to our experiments beyond all doubt. It is not the place here to enter on a further discussion of this phenomenon, the examination and explanation of which remain a subject for later investigation.

This consideration ought not to affect the total average with the colors where half the trials were made with the white disc moved (orange, blue-green, violet, purple); but with red, yellow, green and blue, the white was always at rest. Making the allowance which the trials with the two white circles indicate, *i. e.*, taking into account the average underestimation of the moved disc, and computing after this modification the ratios of the over or underestimation of the colored objects to the normal magnitudes, we arrive at the results in Table XI.

It may be of some interest also to compare the accuracy of the judgment for the different colors. For this purpose we

TABLE II.—*White.*

Division of Exps.	OBSERVER, DR. KIRSCHMANN.						OBSERVER, J. O. QUANTZ.					
	LEFT EYE.			RIGHT EYE.			LEFT EYE.			RIGHT EYE.		
	No. of Single Exp.	Av. Deviation from Norm. Mag	M. V.	No. of Single Exp.	Av. Deviation from Norm. Mag	M. V.	No. of Single Exp.	Av. Deviation from Norm. Mag	M. V.	No. of Single Exps.	Av. Deviation from Norm. Mag	M. V.
		° ′ ″	′ ″		° ′ ″	′ ″		° ′ ″	′ ″		° ′ ″	′ ″
Equal Discs	50	+0 2 8.7	1 14.92	50	+0 1 10.2	0 40.73	50	+0 0 46.55	0 34.9	50	+0 0 28.7	0 57.05
Unequal Discs	50	+0 2 53.8	1 41.8	50	—0 0 5.5	1 19.25	50	+0 4 58.8	1 16.65	50	+0 3 41.5	1 22.28
Av. for Single Eyes	100	+0 2 31.25	1 28.36	100	+0 0 32.35	0 59.99	100	+0 2 52.68	0 55.78	100	+0 2 5.1	1 9.66

	No. of Single Trials.	Average Deviation.		M. V.	No. of Single Trials.	Average Deviation.		M. V.
		Absolute Value.	Val. Rel. to Norm. Mag.			Absolute Value.	Val. Rel. to Norm. Mag.	
		′ ″		′ ″		′ ″		′ ″
Total Average	200	+1 31.8	+0.01355	1 14.18	200	+2 28.89	+0.0221	1 2.72

TABLE III.—*Red.*

Division of Exps.	Observer, Dr. Kirschmann. Left Eye. No. of Single Exp.	Av. Deviation from Norm. Mag.	M. V.	Right Eye. No. of Single Exp.	Av. Deviation from Norm. Mag	M. V.	Observer, J. O. Quantz. Left Eye. No. of Single Exp.	Av. Deviation from Norm. Mag.	M. V.	Right Eye. No. of Single Exp.	Av. Deviation from Norm. Mag.	M. V.
		° ′ ″	′ ″		° ′ ″	′ ″		° ′ ″	′ ″		° ′ ″	′ ″
Red, Small,	25	—0 0 15.84	0 43.08	25	+0 1 26.11	1 6.45	55	—0 3 50.39	1 43.85	55	—0 2 28.74	1 22.20
Red, Large,	25	+0 0 2.44	1 29.	25	+0 3 33.24	1 8.2	50	—0 0 27.34	1 16.	50	+0 0 22.38	1 21.8
Av. for Single Eyes,	50	—0 0 6.70		50	+0 2 29.67		105	—0 2 8.86		105	—0 1 3.18	

TABLE IV.—*Yellow.*

Yellow, Small,	50	—0 2 27.71	1 35.02	50	+0 0 13.70	1 7.38	50	—0 4 1.23	0 55.4	50	—0 2 58.56	1 17.5
Yellow, Large,	50	—0 1 6.17	1 19.8	50	+0 1 7.27	1 15.73	50	—0 1 24.81	1 12.25	50	+0 0 5.16	1 19.85
Av. for Single Eyes,	100	—0 1 46.94		100	+0 40 48.77		100	—0 2 43.02		100	—0 1 26.70	

TABLE V.—*Green.*

Green, Small,	50	—0 3 57.26	1 52.27	50	—0 0 30.31	1 10.75	50	—0 2 51.86	1 33.8	50	—0 2 26.69	1 11.
Green, Large,	50	—0 4 43.76	1 43.15	50	—0 1 51.11	1 10.31	50	+0 0 7.91	0 57.93	50	—0 0 5.93	1 4.75
Av. for Single Eyes,	100	—0 4 20.51		100	—0 1 10.71		100	—0 1 21.97		100	—0 1 16.31	

TABLE VI.—*Blue.*

Blue, Small,	50	—0 4 35.03	1 23.05	50	—0 2 29.17	1 8.85	50	—0 3 13.23	1 19.29	50	—0 3 59.85	1 14.85
Blue, Large,	50	—0 5 45.07	1 34.93	50	—0 1 48.41	2 12.05	50	—0 1 58.14	1 13.	50	—0 0 55.08	1 41.3
Av. for Single Eyes,	100	—0 5 10.05		100	—0 2 8.79		100	—0 2 35.68		100	—0 2 27.46	

TABLE III.—*Red.*

	No. of Single Trials.	Average Deviation.		M. V.	No. of Single Trials.	Average Deviation.		M. V.
		Absolute Value.	Val. Rel to Norm. Mag.			Absolute Value.	Val. Rel. to Norm. Mag.	
		′ ″		′ ″		′ ″		′ ″
Total Average,	100	+1 11.49	+0.0117	1 6.68	210	—1 36.02	—0.0155	1 25.96

TABLE IV.—*Yellow.*

Total Average,	200	—0 33.23	—0.0053	1 19.48	200	—2 4.86	—0.0201	1 11.25

TABLE V.—*Green.*

Total Average,	200	—2 45.61	—0.0269	1 29.12	200	—1 19.14	—0.0127	1 10.87

TABLE VI.—*Blue.*

Total Average,	200	—3 39.42	—0.0356	1 34.72	200	—2 31.57	—0.0245	1 22.11

Table VII.—*Orange.*

Division of Expers.	Observer, Dr. Kirschmann.						Observer, J. O. Quantz.					
	Left Eye.			Right Eye.			Left Eye.			Right Eye.		
	No. of Single Exp.	Av. Deviation from Norm. Mag.	M. V.	No. of Single Exp.	Av. Deviation from Norm. Mag.	M. V.	No. of Single Exp.	Av. Deviation from Norm. Mag.	M. V.	No. of Single Exp.	Av. Deviation from Norm. Mag.	M. V.
		° ′ ″	′ ″		° ′ ″	′ ″		° ′ ″	′ ″		° ′ ″	′ ″
I. Right, Large,	25	+0 9 3.95	1 38.25	25	+0 6 26.94	1 44.18	25	+0 3 43.95	1 27.05	25	+0 2 54.1	1 13.15
II. Right, Small,	25	+0 6 41.8	1 13.28	25	+0 4 1.95	1 18.44	25	+0 1 37.3	1 19.75	25	+0 1 25.6	0 59.05
III. Left, Large,	25	—0 0 16.26	0 55.8	25	+0 2 11.95	1 7.58	25	—0 0 48.5	0 59.78	25	+0 0 40.9	1 0.85
IV. Left, Small,	25	—0 0 37.3	1 23.63	25	+0 3 16.9	1 10.25	25	—0 4 32.95	1 16.68	25	—0 2 29.25	1 16.35
Av. for Single Eyes,	100	+0 3 43.05	1 17.74	100	+0 3 59.44	1 20.11	100	—0 0 0.05	1 15.81	100	+0 0 37.84	1 6.85

Table VIII.—*Blue-Green.*

Division of Expers.	No. of Single Exp.	Av. Deviation from Norm. Mag.	M. V.	No. of Single Exp.	Av. Deviation from Norm. Mag.	M. V.	No. of Single Exp.	Av. Deviation from Norm. Mag.	M. V.	No. of Single Exp.	Av. Deviation from Norm. Mag.	M. V.
I	25	+0 4 24.7	1 17.23	25	—0 0 1.8	1 24.7	25	+0 3 13.85	1 37.3	25	+0 1 2.2	1 23.78
II	30	+0 4 9.8	1 6.95	30	+0 0 36.8	1 37.78	30	+0 0 50.4	1 1.4	30	—0 0 35.55	1 3.88
III	25	—0 6 40.4	1 20.4	25	—0 4 34.4	1 22.2	25	—0 0 22.5	1 43.58	25	—0 0 28.9	1 23.05
IV	25	—0 6 10.8	1 23.8	25	—0 3 28.35	2 10.53	25	—0 2 59.1	2 1.	25	—0 2 13.65	1 33.08
Av. for Single Eyes,	105	—0 1 4.18	1 17.10	105	—0 1 51.94	1 38.80	105	+0 0 10.66	1 35.82	105	—0 0 33.98	1 20.95

Table IX.—*Violet.*

Division of Expers.	No. of Single Exp.	Av. Deviation from Norm. Mag.	M. V.	No. of Single Exp.	Av. Deviation from Norm. Mag.	M. V.	No. of Single Exp.	Av. Deviation from Norm. Mag.	M. V.	No. of Single Exp.	Av. Deviation from Norm. Mag.	M. V.
I	25	+0 3 12.1	1 46.5	25	+0 1 11.25	1 34.75	25	+0 3 2.	0 55.70	25	—0 0 1.8	1 33.63
II	25	+0 3 34.4	1 8.38	25	+0 1 56.3	0 54.36	25	+0 0 13.1	0 51.55	25	—0 0 39.15	1 20.93
III	25	—0 7 5.45	1 1.75	25	—0 5 4.35	1 24.7	25	—0 1 2.77	1 4.25	25	—0 0 13.55	1 1.7
IV	25	—0 5 39.5	1 16.33	25	—0 3 27.1	1 55.93	25	—0 4 35.6	1 39.93	25	—0 3 34.5	1 15.
Av. for Single Eyes,	100	—0 1 29.61	1 18.24	100	—0 1 20.98	1 27.43	100	—0 0 35.82	1 7.86	100	—0 1 7.25	1 17.81

TABLE VII.—*Orange.*

	No. of Single Trials.	Average Deviation.		M. V.	No. of Single Trials.	Average Deviation.		M. V.
		Absolute Value.	Val. Rel. to Norm. Mag			Absolute Value.	Val. Rel. to Norm. Mag.	
		° ′ ″		′ ″		° ′ ″		′ ″
Total Average,	200	+0 3 51.24	+0.0358	1 18.92	200	+0 0 37.79	+0.0031	1 11.33

TABLE VIII.—*Blue-Green.*

Total Average,	210	—0 1 28.06	—0.0138	1 27.95	210	—0 0 11.66	—0.0018	1 28.38

TABLE IX.—*Violet.*

Total Average,	200	—0 1 25.29	—0.0134	1 22.84	200	—0 0 51.53	—0.00785	1 14.75

TABLE X.—*Purple.*

Division of Exps.	Observer, Dr. Kirschmann.						Observer, J. O. Quantz.					
	Left Eye.			Right Eye.			Left Eye.			Right Eye.		
	No. of Single Exp.	Av. Deviation from Norm. Mag.	M. V.	No. of Single Exp.	Av. Deviation from Norm. Mag.	M. V.	No. of Single Exp.	Av. Deviation from Norm. Mag.	M. V.	No. of Single Exp.	Av. Deviation from Norm. Mag.	M. V.
		° ′ ″	′ ″		° ′ ″	′ ″		° ′ ″	′ ″		° ′ ″	′ ″
I	50	+0 8 2.1	1 39.9	50	+0 5 45.	1 33.	50	+0 4 41.	1 15.	50	+0 3 10.1	1 24.35
II	50	+0 3 12.9	0 53.9	50	+0 1 27.6	0 35.9	50	+0 1 34.8	1 13.5	50	+0 0 19.6	1 7.45
III	50	—0 5 35.6	1 4.55	50	—0 3 19.9	1 17.5	50	—0 0 45.5	1 43.3	50	+0 0 32.6	1 44.6
IV	100	—0 3 39.98	1 43.55	100	—0 1 9.85	1 38.91	100	—0 3 17.65	1 26.33	100	+0 0 34.85	1 20.41
Av. for Single Eyes,	250	+0 0 29.85	1 20.48	250	+0 0 40.71	1 16.33	250	+0 0 33.16	1 24.53	250	+0 1 9.29	1 24.20

	No. of Single Trials.	Average Deviation.		M. V.	No. of Single Trials.	Average Deviation.		M. V.
		Absolute Value.	Val. Rel. to Norm. Mag.			Absolute Value.	Val. Rel. to Norm. Mag.	
		° ′ ″		′ ″		° ′ ″		′ ″
Total Average,	500	+0 0 35.28	+0.0045	1 18.40	500	+0 0 51.23	+0.0078	1 24.37

TABLE XI.

COLOR.	OVER- OR UNDER-ESTIMATION, RATIO TO THE NORMAL MAGNITUDE.	
	Observer K.	Observer Q.
Red,	+0.02525	+0.0066
Orange,	+0.0358	+0.0031
Yellow,	+0.00825	+0.0020
Green,	—0.01335	+0.0094
Blue-green,	—0.0138	—0.0018
Blue,	—0.02205	—0.0024
Violet,	—0.0134	—0.00785
Purple,	+0.0045	+0.0078

TABLE XII.

COLOR.	OBSERVER K.		OBSERVER Q.	
	AVERAGE MEAN VARIATION		AVERAGE MEAN VARIATION.	
	Absolute Value.	Ratio of the Normal Magnitude	Absolute Value.	Ratio of the Normal Magnitude
Red,	1′ 6″.681		1′ 25″.9625	
Orange,	1′ 18″.92375		1′ 11″.3306	
Yellow,	1′ 19″.481		1′ 11″.25	
Green,	1′ 29″.1225		1′ 10″.87	
Blue-green,	1′ 27″.9481		1′ 28″.38375	
Blue,	1′ 34″.719		1′ 22″.111	
Violet,	1′ 22″.835		1′ 14″.7469	
Purple,	1′ 18″.4016		1′ 24″.3672	
Av. of all Colors,	1′ 22″.264	0.0131 (= ca. $\frac{1}{76}$)	1′ 18″.6278	0.0125 (= ca. $\frac{1}{80}$)
White,	1′ 14″.175	0.0110	1′ 2″.71875	0.0093 (= ca. $\frac{1}{108}$)

have in Table XII placed together the average mean variations, which remain without exception between the limits of 1′ and 1½′. The accuracy in case of the comparison of two white discs is only very little greater than that of the comparison of a colored disc with a white one. Among the 104 series of experiments there are only three cases where the m. V. is greater than 2′, and fifteen cases where it amounts to less than 1′. The greatest value for the m. V. occurred in the experiments with blue (Observer K.), and amounts to 2′ 12″.05, which corresponds to a relative value of 0.0216 of the normal magnitude. The smallest m. V. we find in the experiments with purple = 35″. 9, that is, 0.0059 of the normal magnitude, or a little more than the smallest visual angle which can be perceived in colored light.[1] It may be remarked here, that everywhere in our tables, where we give the average in minutes and seconds, these absolute values contain a certain small inaccuracy, because the averaged values refer to different normal magnitudes. (For the colors red, yellow, green and blue, the normal magnitudes are 6227″.3 and 6106″; for the other colors they are 6741″.8 and 6099″.3; in the case of two white discs the normal magnitude was always 6741″.8.) In the relative values reported in our tables, this inaccuracy is eliminated.

If we review the results of our investigation in the condensed form given in Tables XI and XII, we are able to draw the following conclusions concerning the influence of the quality of light-sensation on the estimation of surface magnitudes:

There is a small, but decided, influence of color. Red, orange, yellow and also purple have been overestimated by both observers, while blue-green, blue and violet show a decided underestimation. The color of the middle of the spectrum only, green, has different effects on the two observers. The over and underestimation respectively, although they may take part in causing optical illusions, are not con-

---

[1]Uhthoff, "Ueber die kleinsten wahrnehmbaren Gesichtswinkel in den verschiedenen Theilen des Spektrums." *Zeitschrift für Psychologie und Physiologie der Sinnesorgane*, B. I, p. 155 ff.

siderable enough to explain a phenomenon like that of the rising moon. They are indeed very small, varying between the limits of $\frac{1}{28}$ and $\frac{1}{220}$ of the normal magnitude for the Observer K., and $\frac{1}{106}$ to $\frac{1}{560}$ for the Observer Q. But they present themselves with a marked regularity and constancy, and with a decided coincidence of their direction in the results of the two observers.

In order to secure the commensurability of the results for the different colors, it was necessary to apply for all colors approximately the same normal magnitude, which was less than 2° (= about 4 diameters of the full moon) and more than 1½° (or about 3 diameters of the moon). It is possible that the over or underestimation would be found to be more considerable in case of smaller normal magnitudes.

Résumé.

I. When colored surfaces of moderate size are seen on a darker background, the colors of the less refrangible part of the spectrum, and also reddish purple, show a decided tendency towards overestimation in space-extension, while for the more refrangible colors of the spectrum a marked underestimation takes place.

II. Our judgment of the equality of surface-magnitudes shows a rather high degree of accuracy, which is for white but little greater than for colored surfaces.

III. White or colored surfaces of moderate size, seen on a dark background, are underestimated in size when seen in motion towards or from the eye.